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On constraints and affordances in motor development and learning - the case of DCD. A commentary on Wade & Kazeck (2017)

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Abstract

This commentary to the recent article by Wade & Kazeck discusses the role of constraints as a key concept in the understanding of the limitations in DCD. The concept of constraints is linked to affordances and is useful in the understanding of changes due to development and learning and the limitations of DCD, irrespective of theoretical point of view.

The target article by Wade and Kazeck (2016) in this journal reviews the possible causes for developmental motor deficits labelled Developmental Coordination Disorder. They conclude that explanations from a traditional information processing approach are only weakly supported by the data. And they argue that coordination deficits are better explained by a dynamic systems approach - more specifically by problems in perception-action coupling. Finally, they make an attempt to link theory to practice when briefly presenting examples from the literature.

The article by Wade & Kazeck is a welcome contribution as current theoretical explanations of developmental coordination disorder lack consensus. The authors make a strong plea for an approach that is rooted in ecological psychology and considers the perceptual motor system as a self-organizing dynamic system in which perception and action are inherently linked. They contrast this with the information processing (IP) theory as a model of explanation for developmental coordination disorder. Traditional IP theories assume that movements are planned using perceptual information and executed in a sequential way. Later on, IP models have been extended incorporating feedback and feedforward loops. Both theories are 'black box' theories in which perceptual information is somehow linked to motor action. The perception-action cycle of the dynamic system theory involves three components: the perceptual motor system, the task and the environment. As such it is an integrated theoretical framework. IP theories consider the environment only as a source of task relevant or task irrelevant stimuli. In my view, both theories have their strengths and weaknesses. In this commentary I will focus on the role of constraints as a key concept in the understanding of the limitations in DCD.

Any theoretical explanation of DCD will need to address both the developmental and the coordination aspects of DCD (for a recent discussion see Whithall & Clark, 2016). Motor coordination refers to combining subsequent parts of the same movement, or the movements of several limbs or body parts in a manner that is well timed, smooth, and efficient to achieve an intended goal. The developmental aspects are the changes over developmental time in the system. These changes may occur at different levels. For example in the self-organized system at the neural level the variety, the number and the strength of synaptic connections may change, at the muscular level it may be the muscle strength and endurance that changes, and at the behavioural level the stability of coordination and the speed and accuracy to switch to another pattern of coordination or target location may change with age.

On development and affordances

The perception-action system exploits affordances that are present in the environment, and accommodates the forces and conditions that act upon the perceptual and motor system, such as side wind or gravity and low vision in fog or night fall. An interesting question is how the system 'knows' about the affordances to interact with the environment. The answer from ecological psychology is that (innate) direct perception provides this knowledge. Indeed, babies and toddlers already show a remarkable capacity to perceive affordances such as 'grabability' of moving toys and 'climbability' of slopes. If, however, this capacity to perceive affordances was fully developed at early age, parents would not have to pay so much attention to the safety of their children. The point I want to make is that recognition of affordances often needs to be learned. This learning comes about mostly by trial and error, by observing how others exploit the environment, and sometimes through (written, oral or visual) instruction. Feedback is information generated by the moving body and the perceived environment, the well known perception-action cycle. During development children learn to exploit such information. Exploration and imitation are powerful drives for the child to develop.

Another aspect of development is that not only the perceptual motor system changes with age, so does the environment of the growing child, and with it the affordances. A playground for two years old children differs from that for ten years old children, not just because the children differ in their interests or size (toys and objects for outdoor play are usually scaled to body size), but also in various capacities such as precision, predictive control and anticipated reaction to actions of others, dual tasking, social interaction, and more. Thus, for a developing child affordances in the environment may come and go. Development and learning of motor skills largely result from a dynamic and self-organized system that 'knows' to a large extent how to exploit affordances in the environment to reach goals efficiently.

The selection of affordances from the environment is not self-evident. There is still the question how we select an optimal solution for a movement problem from many afforded by the environment and the perception-motor system. Optimization principles such as minimal energy consumption, maximal comfort, level of safety and anxiety may determine the selection of the way the movement problem is solved.

On coordination and constraints

Newell (1986) distinguishes three aspects for movement: (1) coordination, which constrains the possibilities (degrees of freedom) of the perceptual-motor system such that functional behaviour emerges; (2) control, which determines how the chosen coordination pattern is used, for example how fast the movement is going to be; (3) skill, which emerges when the optimal set of control parameters has been found and is further optimized.

Constraints may act at the level of the perceptual-motor system, but also at the level of coordination and control. The main strength of IP models is that they use a systems analysis approach that decomposes the system into functional parts which then may be tested on functional limitations or deficits, that is, deviant constraints. These limitations are then assumed to contribute to the functional deficits such as in DCD. Newell (1986) distinguishes between structural and functional

constraints. Structural constraints are relatively time independent. They refer to 'hard-wired' constraints in the perceptual-motor system such as low muscle force, low vision or limited speed of neural signal transduction due to immature myelination. Functional constraints may change on a much shorter time scale. They depend on current weights of connections in the neural networks and are relatively easily adapted through experience and learning (i.e. when children learn new complex skills by imitation, training or instruction).

On motor development and learning

The concepts introduced in the previous paragraph can be related to motor development and learning. Development may be defined as the result of a self-organizing process of interaction between biological growth (maturation) and spontaneous learning (exploration), generally in the direction of increasing functionality. It is characterized by a relatively slow rate of change. Learning can be distinguished from development as the process of change that is independent of biological growth. It is based on relatively fast changes in neural connections.

Structural or functional deficits should be seen as limiting constraints that lead to functional reorganization. Functionality should be understood in the context of tasks and environmental constraints and affordances. Figure 1 illustrates how constraints may be revealed in a procedural learning experiment.

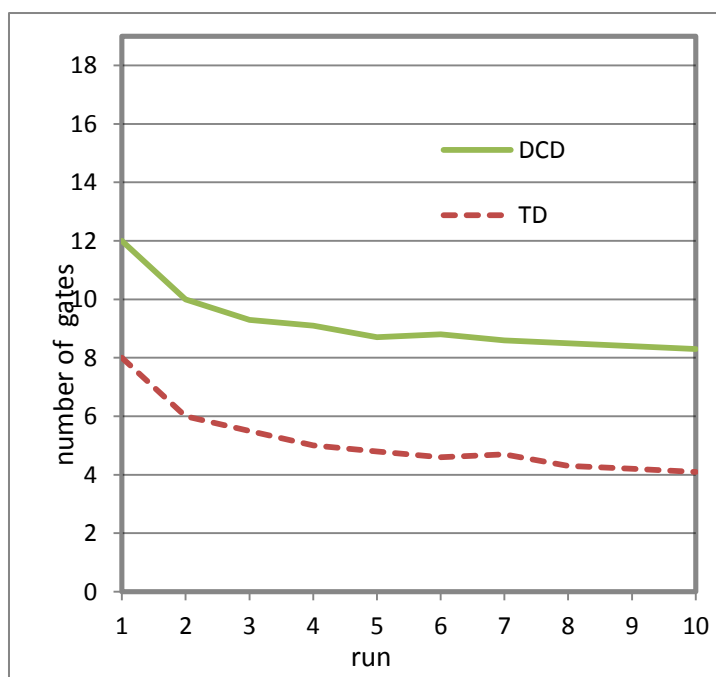


Figure 1 Short term motor learning curves of dynamic balance control in children with and without DCD. Data from Jelsma et al. (2015). Children played a Wii-Fit ski slalom game, standing on a Wii-Fit balance board (a forceplate device) and control the avatar on the screen by lateral displacement of their weight. The dependent variable is the number of gates passed out of 19. The structural constraint of the perceptual motor system is apparent from the limit of the learning curve, which is about 8 gates missed in the DCD group and 4 missed in the typically developing (TD) group. The improvement from the initial level of performance to the ultimate level at the limit may be interpreted as the functional constraint. The rate of learning is similar in both groups.

Skills need to be acquired. Major theories of motor learning were proposed by Fitts (1984) and Bernstein (1967). The first one roots in IP theory. Three stages of motor learning are distinguished: (1) a cognitive phase in which one explores possible strategies and selects an effective solution of the movement problem; (2) an associative phase in which the chosen movement strategy is optimized; (3) an autonomous phase in which the component processes become less dependent on cognitive control and to interference from other ongoing activities. Bernstein's theory departs from the self-organizing principles of dynamics theory. It distinguishes between three stages as well, which largely overlap with those of Fitts. However, Bernstein's theory adds the self-organizing mechanism of freezing degrees of freedom of the system in the initial stage of learning as this helps to gain coordination and control. As the skill is learned the more distal parts of the system become gradually involved to fine-tune the movements.

As Wade and Kazeck observe, few studies have addressed the coordination problems of DCD from a dynamic systems approach. The strength of this approach is mainly in the understanding of rhythmic coordination, such as walking and coordination between limbs rather than in goal directed movement. Rhythmic coordination between limbs and between an effector and an external stimulus have been extensively studied in adults. These studies show that the structural and functional constraints determine the regions of stability of coordination, such as in-phase and anti-phase coordination (Kelso, 1984). These patterns are largely innate and are found throughout the animal kingdom. When reaching the limits of the system (constraint) a natural switch to a more stable coordination pattern is observed, e.g. from anti-phase to in-phase. A few interesting studies have been published on learning new rhythmic coordination patterns (e.g. Kostrubiec et al, 2013), with fascinating results. They show that learning a new rhythmic coordination pattern, e.g. tapping at 45 degrees phase difference, progresses through an increase of stability and accuracy of the required pattern at the cost of that of closely related coordination patterns. Another phenomenon is entrainment, the slow shift of coordination towards a new pattern that may become stable with experience. This shows that coordination patterns are flexible in different ways. This has the potential of being exploited in intervention of coordination problems. Future studies may explore the limitations that children with DCD may have in producing stable patterns of coordination in rhythmical tasks, and investigate if such principles of learning and change are useful in the intervention of DCD.

The case of DCD

My understanding of DCD as a developmental disorder is that the coordination problems and skills acquisition problems are caused by structural and functional constraints of the perceptual motor system. These constraints are likely to differ between the individual children with DCD. Both the IP and the dynamic systems approach offer hypotheses about the deficits or deviant constraints that affect the individual level of coordination, control and skill, that may be tested.

There is a clear cognitive component in learning, both conscious and unconscious, when solving the initial movement problem. In DCD there is evidence of problems in Fitts' motor learning stages (1) and (3), whereas the learning rates for stage (2) are equal (Smits-Engelsman et al., 2015; Jelsma et al., 2015; for a review of motor learning problems and DCD see Biotteau, Chaix & Albaret, 2016). The clinical observation of proximal control of limb movement seen in children with DCD points at freezing degrees of freedom.

Although the label DCD highlights coordination problems in the developmental period as the central issue, the description of the characteristics of DCD in DSM-IV and DSM-5 and in the literature is more general and places emphasis on task performance deficits. The assumption is that the coordination problems cause the poor performance of the children with DCD. This seems to be the position Wade & Kazeck take. For a proper understanding of the problems that children labeled DCD may have it is important to acknowledge individual differences, both strength and weaknesses, from a much wider perspective. The fact that a substantial proportion of the DCD children do grow out of it (Cantell et al., 1994; Geuze & Börger, 1993) suggests that there are several causes for the coordination problems, such as deviant development, slow rate of development/maturation, slow rate of motor learning, physical constraint (lack of force, micro-lesion, amblyopia), environmental constraint (food, housing, money), some of which may be overcome in due time.

To understand functional limitations in perceptual-motor development and learning, we need to know about the constraints within the system at the different levels, that is, the structural level and the functional level (as defined by Newell). The functional level is related to tasks and movement goals. In the case of DCD clear structural constraints are excluded by Criterion D of DSM-5. Please note that differences in brain activation (fMRI) between groups of children with and without DCD (for reviews see Brown-Lum & Zwicker, 2015; Biotteau et al., 2016) as such may indicate structural constraints, but are no proof that they cause the functional limitations in DCD, as neural networks are plastic. Rather, the constraints of children with DCD are to be revealed at the functional level. Additionally, environmental constraints may affect typical motor development, such as restricted opportunity for exercise and exploration.

The impact of functional constraints will be task dependent. Both the dynamic systems approach and the IP approach may reveal constraints. For example, the tapping studies by Volman & Geuze on bimanual and visuo-manual coordination (1998a,b) in children with and without DCD reveal a weaker coupling strength between the components, i.e. between the hands and between a single hand and an external visual stimulus in children with DCD. The perceptual motor-system affords a coordinated behavior up to a certain frequency of tapping. This critical frequency is the functional constraint of this task and is lower for the DCD group. Also, the time to recover the coordination pattern after a perturbation is longer in this group. But please note that each of these deviant characteristics were present in only about half of the children with DCD. Henderson, Rose & Henderson (1992) studied simple reaction time, a typical IP variable. They showed that reaction time was longer and related to the MABC-test performance in children with DCD compared to TD children at school age. Both studies point at slow conduction (structural constraint) and/or inefficient neural networks (functional constraint).

How about the role of development? Visser and colleagues (1998) studied the longitudinal changes over a period of 2.5 years of adolescents with and without DCD during the growth spurt using performance measures of the M-ABC tasks; an IP approach. They show that performance over the full range of perceptual-motor tasks of the M-ABC improves in many children with DCD as they mature, but not in the control children. They conclude that the initial poor performance of the children with DCD may be due to late maturation of the neural system, which points at a structural constraint.

These studies illustrate the importance of finding out about the individual deficits in constraints. These constraints may be rate limiting development (children who lag behind but will catch up later) or be structurally or functionally deviant (children who lag behind and do not catch up). Intervention should somehow address the affected constraints. This may be done by directly, e.g. by training to improve simple reaction time or to shift the critical frequency to a higher frequency; however, this does not guarantee transfer to, and thus improvement of, ecologically valid task performance at all. Recent evaluation of the evidence base of interventions for children with DCD indicates that a task oriented intervention is to be preferred over a function oriented intervention (Smits-Engelsman et al., 2013).

In the last part of their paper (paragraph 3) Wade & Kazeck propose a number of ways to address intervention from an ecological perspective. This is important as this theory and the IP theory afford different questions to be asked about causation. Ultimately this should lead to evidence based interventions that address the factors that constrain the acquisition of typical motor skills, not only through training of specific tasks, but also by finding alternative strategies that solve the motor problem of the task at hand. Future studies may address the discovery and exploration of affordances by individuals with DCD in tasks they need to improve most, for example using the joyful opportunities offered by VR games and followed by training in realistic environments.

An important characteristic of the movement behavior of children with DCD is the larger variability when repeating sequential movement. This variability may be linked to (in)stability of rhythmic coordination, but this has not been investigated yet. Understanding of the common basis or independence of the variability/stability of coordination issues should be addressed in future studies.

Transfer of intervention induced increase of functionality between tasks is another topic that is largely unexplored in this field.

Concluding remarks

It is true that studies have failed to demonstrate valid and reliable causation, but is this due to the focus on IP theories? First of all, the search for a unitary cause in the case of DCD is wrong, given the individual differences. Secondly, causality is very difficult to prove. We should aim for theory driven and ecologically valid explanations. Accordingly, I would like to promote a wider approach to the understanding of DCD. Such an approach should accommodate the individual differences and different explanations for DCD. Our understanding should be increased by longitudinal studies of perceptual motor skill acquisition and learning; the use of different tasks and conditions of difficulty that reveal the constraints; and the use of varied theories that are best suited to address the specific research question at hand. Ultimately, to understand the causation of the functional limitations of children with DCD - how they emerge and how they develop – is to reveal the constraints in a variety of tasks and conditions, and find out about their functional consequences preferably through keen experimental manipulation. In my view this can be done from a dynamic systems, and an IP perspective.

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